A CASE STUDY OF BENEFIT-COST ANALYSIS

Soil Bioengineering As An Alternative For Roadside Management

Prepared by

Environmental Affairs Office
and
Design Office

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Washington State
Department of Transportation

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EXECUTIVE SUMMARY

As an environmentally compatible and cost efficient alternative for roadside management, soil bioengineering has become increasingly important and attractive. Soil bioengineering uses live plants and plant parts as building materials for engineering and ecologically sound solutions in order to provide erosion control, slope and stream bank stabilization, landscape restoration, and wildlife habitat. However, not all decision makers are aware of the specific benefits of this approach. This case study applied a benefit-cost analysis to an experimental soil bioengineering demonstration project to determine whether it is indeed an economically efficient alternative to traditional roadside management.

Traditional roadside management methods (geo-technical solutions) were used as the base line in this analysis while soil bioengineering treatments were treated as an investment alternative. Cost savings, along with other environmental benefits provided by the soil bioengineering project, were assessed and compared with the costs of construction. The impacts of life cycle, effectiveness, and discounting were incorporated into the analysis to ensure comparability between both treatments.

The analytical results demonstrated that when technically feasible, soil bioengineering methods could be adopted to produce equal or better economic and environmental results. The following key results were derived from the analysis:

* Based on life cycle analysis, all three projects achieved substantial savings in costs by using the soil bioengineering method.

  Soil bioengineering will more likely be efficient when a traditional approach requires a lump sum investment.

  While cost savings is the most substantial benefit for the sites, environmental benefits also showed high value.

  The environmental benefits associated with soil bioengineering methods are likely to be more significant in urban and industrial areas rather than rural areas due mainly to air quality and reduction in runoff.

  For every dollar invested in roadside stabilization, the soil bioengineering method generated more in benefits than the traditional method.

The findings of the research project and the economic analysis have indicated that soil bioengineering is an efficient and environmentally beneficial tool for roadside management.

INTRODUCTION

Transportation systems provide tremendous opportunities to society. Roads, however, are often linked to increased rates of soil erosion and accumulated adverse aesthetic and environmental impacts to both aquatic and terrestrial resources. Development priorities usually emphasize access, safety, and economics. While environmental concerns typically refer to operational and maintenance problems, the former three priorities are also considered important criteria. Road maintenance personnel face a substantial task in maintaining roads under their jurisdiction. The Washington State Department of Transportation (WSDOT) manages over 7,066 miles of roadway and 97,500 acres of roadside. The erosive slopes found adjacent to these roadways in 1998 included 733 mass wasting entries.[1]

Historically, WSDOT engineers relied primarily on hard/conventional solutions, such as rock, for slope and landslide stabilization. Erosion and sediment control can be expensive using these solutions. Soil bioengineering is an attractive alternative to conventional engineering solutions for erosion and sediment control and can, in fact, eliminate sediment control altogether.[2] Soil bioengineering uses live plants and plant parts as building materials for engineering solutions to provide erosion control, slope and stream bank stabilization, landscape restoration, and wildlife habitat. By definition, soil bioengineering is an integrated technology that uses sound engineering practices in conjunction with ecological principles to design and construct vegetative living systems to prevent erosion, to stabilize shallow areas of soil instability, and to protect and enhance healthy systems. The techniques can reduce or eliminate maintenance needs and provide broader functions including a more attractive, natural look than conventional treatments alone. Most soil bioengineering techniques mimic nature by establishing a foundation upon which nature can build to become self-sustaining. Essentially, the vegetation becomes the structure. Typically this is achieved by using locally available materials and a minimum of heavy equipment, offering roadside managers an effective long term and inexpensive way to resolve local environmental problems.

However, soil bioengineering should not be viewed as the sole solution to most erosion and slope stability problems. It represents only one important element. This technology must be considered in combination with conventional engineering such as hydrology/hydraulics, geotechnical and fluvial geomorphology, to name a few. The addition of techniques, such as rock or concrete structures, is frequently required to increase effectiveness or reduce overall cost. Appendix 1 provides an overview of advantages and limitations of a soil bioengineering approach.

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[1] This number does not include chronic areas of surface erosion, especially cutslopes that are ideal for soil bioengineering.

[2] Lewis, L. 2000. Soil Bioengineering An Alternative for Roadside Management: A Practical Guide. *USDA Forest Service, Technology & Development Program.* 7700-Transportation Management. 0077 1801—SDTDC.

With the Endangered Species Act (ESA) listing of several runs of Northwest Salmon, sediment pollution control has become critical. The expenditure necessary to face this issue is expected to increase sharply while the transportation budget deals with greater uncertainty. Therefore, as an environmentally sensitive and cost efficient alternative for roadside management, soil bioengineering becomes increasingly important and attractive.

In 1995, a Soil Bioengineering task force was formed to study opportunities for the application of soil bioengineering methods along Washington roadways. In 1998 landscape architects and engineering geologists applied for, and were granted funding for a soil bioengineering research project through the WSDOT Research Office to explore the use, and application, of these techniques on upland slopes within the highway right of way. This case study is a subset of the research project.

Benefit – cost analysis is a powerful tool to assist in the decision making process. Environmental benefits lack market value and are therefore often ignored which allows for improper pricing of varying options. Costs tend to be the driving force for choices. When benefits are quantified and included into the comparison, more efficient decisions can be made.

This benefit – cost analysis evaluated costs and benefits of three soil bioengineering cases in order to provide essential information that can be used to:

* Assist decision-makers to assess and justify the promotion of soil bioengineering as a cost-saving and environmentally sound alternative for surface erosion and shallow mass rapid landslide stabilization.

  Evaluate cost-efficiency and select the best approach from traditional (geotechnical) treatment costs, soil bioengineering costs, or their combinations.

  Educate WSDOT personnel, other land managers and the public about the integration of economic efficiency, environmental values, and aesthetic values of soil bioengineering.

STUDY METHODOLOGY

Site Selection and Treatment Design

This study looked at three sites in Washington to determine whether soil bioengineering could be an alternative investment to traditional methods for roadside management. Even though the researchers would have liked to analyze more sites, the study was limited to the three sites because logistics of construction and monitoring on a greater number of sites was beyond the scope of the research project.

The sites were located at Chelan, Raymond, and Forks/Lost Creek and were chosen after a team field review of over 88 potential sites throughout most of Washington State. The Principal Investigator selected these sites based on the following criteria:

- Safety of the public and work crews
- Visibility and accessibility for educational opportunities
- Representation of the disparate soil moisture conditions, climate, and erosion types common to Washington State
- Illustration of soil bioengineering techniques that could be used on large erosion sites, small erosion sites, and combined soil bioengineering and traditional engineering treatments
- Allocated dollars and the availability of additional funding
- Recommendations by WSDOT personnel[3]

The sites chosen have varying characteristics. Two are located on the west side of the state, receiving higher amounts of precipitation, (Raymond and Forks/Lost Creek) and one is on the east (Chelan). Two of the sites are considered large sites (Raymond and Chelan). Forks/Lost Creek is a smaller site that combined soil bioengineering with a rock apron and some gully packing with rock (geotechnical treatment). Two of the sites were examples of surface erosion (Forks and Chelan) and the other site is an example of shallow, rapid, landsliding (Raymond). Design and construction details can be found in Appendix 2.[4]

Cost Assessment

As this analysis is based on comparison, costs were determined for the traditional method as well as for soil bioengineering. Since soil bioengineering was implemented at the selected sites, actual costs could be applied. Hypothetical traditional treatment costs were determined for comparison by engineers and landscape professionals so that the total costs for these treatments could be estimated. The costs included both capital cost and the operation and maintenance cost at each site. Descriptions of the conventional engineering treatments that would have been used can be found in Appendix 2.

WSDOT personnel were contacted by phone to assist in estimating the traditional treatment costs. They were asked what treatments would have been used on the three

[3] Lewis, Elizabeth, Shannon Hagen, Mark Maurer, and Sandy Salisbury. 2000. Washington DOT Investigates the Soil Bioengineering Alternative. *Public Works Magazine,* August, 42-44.

[4] Specific details with regards to site assessment, design and construction can be found in the research report: Soil Bioengineering for Upland Slope Stabilization. By Lisa Lewis, Sandra Salisbury, Shannon Hagen and Mark Maurer. April 2001. (WA-RD 491.1)

sites if the department had chosen to treat those slopes using traditional methods. Treatments were suggested based on climate, erosion condition, proximity to a watercourse, soil type and conditions, and past treatment experiences. Costs were estimated using bid tabs of nearby projects for those particular geographic locations. Listings of the costs of both methods can be found in Appendix 3.

Benefit Assessment

In order to determine which benefits would be assessed for this analysis, a thorough review of existing literature was completed. Timing and budget did not allow for independent studies to be completed for these particular sites. Therefore, benefits achieved at other locations, which employed soil bioengineering techniques, were assumed to occur at the three study sites. The benefits of roadside management, determined from a literature review, that were assessed in this study are:

Cost Savings
Runoff control
Air pollutant uptake
CO_2 sequestration

These benefits were estimated based on data collected for this study or derived from the results and findings of similar studies.[5] There are many other environmental and aesthetic values that are associated with soil bioengineering treatments but they were not assessed because of either intangibility or time constraints.

Cost savings is the most significant benefit of soil bioengineering since it tends to be less costly to build, usually lasts longer, and requires less maintenance. In order to provide a baseline for determining the cost savings, the effectiveness was assumed to be the same for both the traditional and soil bioengineering methods. They are both designed for roadside stabilization based on required standards and are assumed, for the purposes of this study, to perform at that standard. Future research could test actual performance. Since cost savings is one of the key reasons to consider soil bioengineering, estimates were compared based on the cost assessments for both traditional and soil bioengineering treatments.

Stormwater runoff control is important in order to eliminate the addition of construction-related sediment to stream systems as required by WSDOT best management practices (BMP's).[6] Stormwater runoff reduction benefits were assessed

[5] Sotir, Robbin. Personal Communication 2000.
McPherson, Gregory E., et. al. 1999. Benefit-Cost Analysis of Modesto's Municipal Urban Forest. *Journal of Arboriculture,* 25(5): 235-248.
California State Department of Transportation. 1998. *Cost of Stormwater Treatment for California Urbanized Areas*.
U.S.EPA. 1999. *Economic Analysis of the Final Phase II Stormwater Rule*. Office of Water. EPA 833-R-99-002.
[6] Tveten, Richard K. Personal Communication 2000.

using runoff coefficients of different land covers, local hydrograph, sediment treatment requirements, and unit value of stormwater treated. Appendices 4 and 5 have more details on benefits and their value calculations.

Air quality is affected by erosion and by vehicles traveling on roads. Pollutants deposited include Ozone, NO_2, and PM_{10}. To reduce impacts, mitigation can be an important tool. Trees remove pollutants from the atmosphere and also eliminate or reduce the source of sediment runoff from stormwater. Air pollutant uptake benefits were assessed based on the number of trees planted, growth rate and canopy cover information, unit value of pollutant taken up, and effectiveness. Effectiveness was determined by evaluating source elimination and pollutant uptake effects.

In addition, carbon sequestration benefits were assessed based on the assumption that 80 percent of carbon will be released at the end of the life cycle (removal of trees). The unit value of carbon sequestration was derived by other studies (see Appendix 4).

A benefits transfer model was used to establish site-specific values for each of the environmental benefits (Appendix 5). This model transfers available information from studies already completed in another location and/or context to estimate economic values for services at the study site. It is especially useful when the expense of doing an independent study is too high or if there is limited time available. It is a common approach and can be used in a way that is sensitive to the context of application. Transferred values were adjusted according to the changes of key factors. Appendix 6 contains additional information on benefit transfer.

Comparability

The primary analysis of this report was to compare the costs needed to obtain the presumed same stabilization benefits for each method. Soil bioengineering was evaluated as an alternative investment option in this benefit cost analysis. Soil bioengineering projects were designed to produce the same roadside stabilization effect as their counterparts. Therefore, the cost savings resulting from adoption of soil bioengineering projects was evaluated as a net benefit. The benefit of stabilization was assessed using the cost pricing method for both soil bioengineering and traditional approaches.

The key factors in assessing and comparing costs and benefits for this study included:

Effectiveness – adjusting the benefit in terms of effectiveness of the technology
Life cycle analysis – adjust the cost in terms of life cycle of the technology
Discounting – make benefit and cost streams over the project life comparable

Effectiveness

The benefits of roadside management approaches should be adjusted in terms of the effectiveness of their functions. Soil bioengineering techniques are assumed to be as effective as traditional engineering methods, when suitable techniques are used on appropriate sites for roadside stabilization and treatment of runoff and when they are installed correctly.[7] Studies have shown that this method can be used to stabilize slopes and mitigate soil erosion.[8] Furthermore, since soil bioengineering uses living plants, it has additional benefits that inert structures do not have. For example, plants can provide air pollutant uptake and carbon sequestration. Plants also provide visual benefits such as distraction screening, guidance and navigation enhancement, along with being aesthetically pleasing. They reduce stormwater runoff via root uptake, the canopies, and the duff layer.

When the benefit transfer method was applied to evaluate environmental benefits, effectiveness for related functions was assessed based on the different conditions between the original study sites and the sites of this particular study. Table 1 illustrates which assumptions of effectiveness were used in this study. Appendix 4 delves into further detail on the values used.

Table 1: Effectiveness Assumptions Used in This Study

	Roadside Stabilization	Runoff Treatment	Air Pollutant Uptake	CO_2 Sequestration
Chelan	100%	100%	34%	100%
Raymond	100%	N/A	N/A	N/A
Forks	100%	50%	9%	100%

At the Raymond site, benefits for runoff treatment, air pollutant uptake and CO_2 sequestration are not shown. This is because the slope was previously vegetated with grass and some shrubs, so these particular benefits were already taking place to a certain degree. For the study, it was assumed that no improvements existed in these categories for Raymond.

[7] Sotir, Robbin. Personal Communication 2000.

[8] Gray, Donald and Robbin Sotir. 1995. Biotechnical Stabilization of Steepened Slopes. Prepared for the Transportation Research Board 74th Annual Meeting. Washington, D.C., January 22-28.
Sotir, Robbin. 1998. "Brushing up on erosion control." *American City and County*. February: 18-25.

Life Cycle Analysis

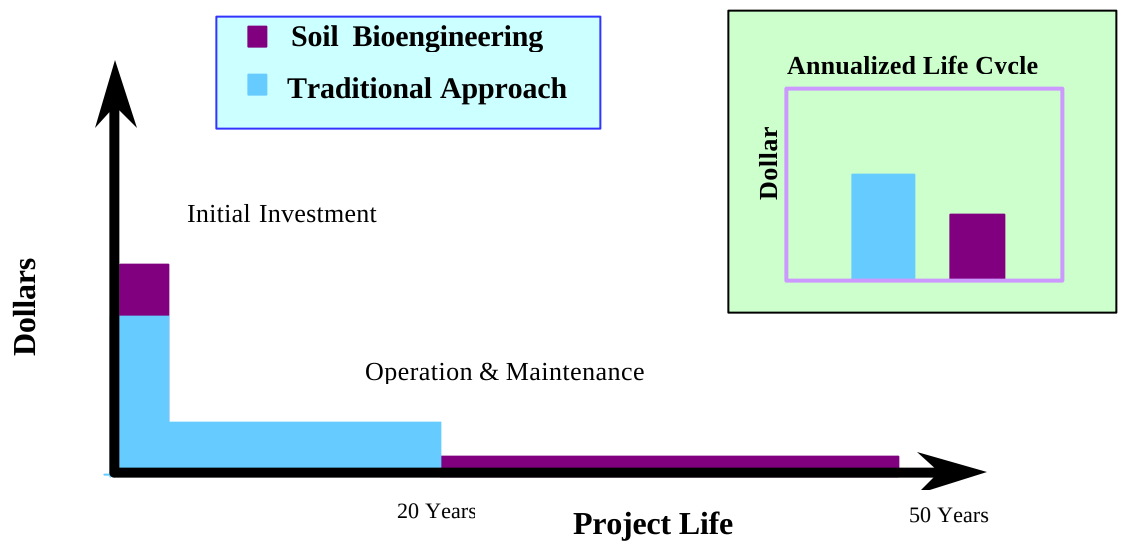
Life cycle analysis is used to adjust costs in terms of the life cycle of both traditional and soil bioengineering methods. The initial investment for a soil bioengineering project is frequently higher in both the planning and construction phases than traditional engineering, especially if a wide range of professional expertise is required. However, the project life is historically longer with a living system, such as soil bioengineering, and in some cases seems to be infinite.[9] Therefore the annualized life cycle cost is lower with this method.

For this study, the life cycle for soil bioengineering was conservatively set at 50 years[10] whereas the hypothetical traditional treatment's lifespan is 20 years.[11] The 20 year life cycle is what is generally used in planning and forecasting projects at WSDOT. The sensitivity analysis shows what effect different life cycle values have on the overall results.

Figure 1 illustrates the concepts of life cycle costs for soil bioengineering and traditional methods.

Figure 1:

Life Cycles - Soil Bioengineering compared to Traditional Approach



[9] Sotir, Robbin. 1998.
[10] Sotir, Robbin. Personal Communication 2000.
Schiechtl, H.M. and R. Stern. 1997. *Ground Bioengineering Techniques for Slope Protection and Erosion Control.* Blackwell Science Publications. ISBN: 0-632-04061-0.
[11] Dowling Associates, Inc., et.al. 2000. *WSDOT Mobility Project Prioritization Process: B/C Software User's Guide.* Oakland, California

The figure graphically displays the higher initial investment for soil bioengineering, but it also shows its longer life and less costly maintenance. The smaller figure on the right displays that when costs are annualized for their life cycle, the soil bioengineering option has lower costs because of its longer projected life. This figure attempts to illustrate in a simple form why soil bioengineering produces greater economic benefits.

Discounting

Discounting was used to make benefit and cost streams over the project life comparable. In other words, it forces the future price down without undervaluing the future so that it is comparable to the present price. The benefits of different times thus become comparable. The discounting rate is the pace at which the value of future gains is reduced and in this analysis, the rate is four percent.[12] This rate was evaluated in the sensitivity analysis to verify what effects varying discount rates would have on this study.

Data Sources

The data sources used included actual costs, estimated costs using historic data, U.S. Environmental Protection Agency (EPA), USDA Forest Service, California Department of Transportation, experts' opinions, along with other sources. These sources are listed in the reference section at the end of the report.

Sensitivity Analysis

Finally, a sensitivity analysis was completed to test uncertain variables. In order for this study to be effective, certain variables were initially set and then analyzed at the end to determine how results would change when some of these assumptions change. Sensitivity analysis is required because of uncertainty, risk, and accuracy of estimations. Results for different values vary and are tested for the uncertain variables. This process may show how results of an analysis change when some of the assumptions on which the analysis is based change. The factors, which are most influential to the results, are established and the key determinants identified. These factors were:

- The effect of life cycle on cost savings
- The effect of the air pollutant uptake effectiveness value on the benefit – cost ratio
- The effect of discount rate on the benefit - cost ratio

In this report, the sensitivity evaluation is presented after the data analysis.

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[12] Dowling Associates, Inc., et.al. 2000. *WSDOT Mobility Project Prioritization Process: B/C Software User's Guide.* Oakland, California

DATA ANALYSIS - FINDINGS

Cost Savings

In order to determine the benefits of the projects in the limited time available, it was assumed that the mechanical stabilization benefits of soil bioengineering would be the same as the stabilization benefits of the traditional method. By accepting this assumption, it was possible to make a comparison based on cost savings of one method over another. Costs included capital as well as operation and maintenance, or plant establishment (where applicable) with probable costs varying from one project to another. Soil bioengineering treatments require little operation and maintenance investment and so additional costs are generally in the form of initial plant establishment, and weed control. The following two tables summarize the annual life cycle costs for the projects based on a life cycle of 20 years for traditional treatment and 50 years for soil bioengineering:

Table 2: Summarized Costs of Traditional Treatments

	Chelan	Raymond	Forks
Capital Cost	$ 16,927	$ 153,635	$ 48,979
O&M	$ 2,990	$ -	$ 22,745
Total Cost (w./ sales tax)	$ 23,224	$ 179,139	$ 86,785
Annualized Cost for Life Cycle	$ 1,161	$ 8,957	$ 4,339

* *Total Cost includes a calculated mobilization cost (10%) and sales tax (6%).*

Table 3: Summarized Costs of Soil Bioengineering Treatments

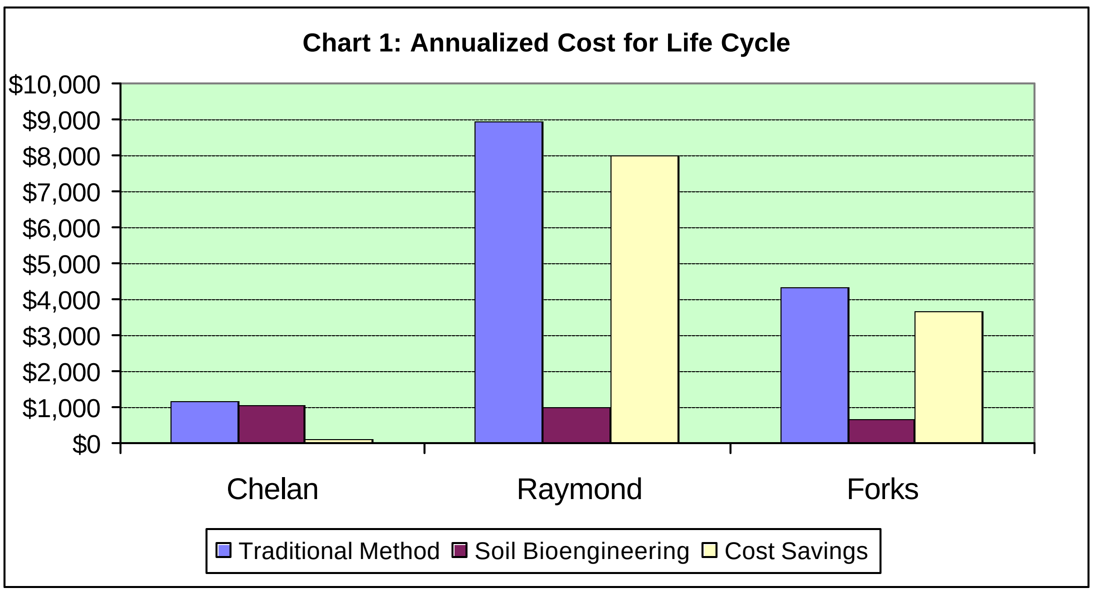
	Chelan	Raymond	Forks
Capital Cost	$ 46,983	$ 44,510	$ 30,774
O&M	$ 5,233	$ 4,501	$ 2,362
Total Cost *	$ 52,216[13]	$ 49,011	$ 33,137
Annualized Cost for Life Cycle	$ 1,044	$ 980	$ 663

[13] After a period of heavy rains on a snow layer (in March 2001), a section of bender board at Chelan failed. Approximately 40 feet out of a total of 1,875 feet failed. This section was located near a seep in the area that was not treated using compost. The section was repaired using live fascines, compost and additional bender board with the costs totaling approximately $1500. This cost is included as part of operation and maintenance and was, therefore, not listed as an additional expense.

* *Total Cost is based on actual costs, which includes mobilization and sales tax.*

Traditional treatments require an operation and maintenance cost that includes ditching and upkeep of erosion control devices, such as maintaining the pond (cleaning out sediment and disposing). At Forks, the operation and maintenance costs are especially high because the material, which is very fine-grained silty clay and sediment, would have to be disposed of where no possible contamination of water sources would occur.[14] Soil bioengineering requires an operation and maintenance cost that includes plant establishment. Detailed breakdown of these costs can be found in Appendix 3.

A graphical presentation can give a clearer picture of the annualized cost differences for the projects and treatment type. Chart 1 also shows the cost savings of the different methods and the different sites.



As can be seen, the Raymond and Forks sites both have a total cost savings that heavily favors the soil bioengineering treatment. The tables and chart show the differences in costs not only by treatment type but also by site. It is clear that costs are highly variable and are reflective of the characteristics of that site. For example, the costs of using soil bioengineering at Chelan is comparable to the other sites, but is higher than the hypothetical traditional treatment for this particular site because the traditional treatment would include grading and hydroseeding. Initial costs of implementation of the soil bioengineering method are high, but Chelan does show a slight cost savings over its lifetime. This is because the costs get annualized over more years.

[14] Nordstrom, Don. Personal Communication 2000.

Raymond, on the other hand, has very high traditional treatment costs in comparison to the other sites. This is because of the high cost of heavy rip rap for this size area in this particular geographic location along with the high freight costs.

In general, the highest cost for the soil bioengineering method at these sites was for labor costs.

Based on life cycle analysis, all three projects achieved a savings in costs by using the soil bioengineering method.

By simply comparing costs (not even bringing in environmental benefits), it is clear that it was cost effective to implement the soil bioengineering method over the traditional method at these three sites.

Environmental Benefits

As stated in the methodology, the environmental benefits include runoff control, air pollutant uptake and CO_2 sequestration. They are part of the total project benefits, which also includes roadside stabilization. The roadside stabilization benefit was calculated as the benefit achieved from cost savings (see previous section). The environmental benefits were calculated using methods outlined in Appendix 4. All of these benefits combined were used for the benefit – cost comparison in the next section.

Since two of the three environmental benefits are related to air quality, location is important. Sites that are situated in urban or industrial areas, rather than rural areas, tend to have higher environmental benefits associated with the soil bioengineering method unless they are located in areas of high winds resulting in suspended dust particles (as in some parts of Eastern Washington).

Table 4 summarizes solely the environmental benefits of the soil bioengineering method, without including the stabilization benefits achieved through cost savings. The Raymond site is not shown because the slope was previously vegetated and so these particular benefits were already partially taking place. It was assumed that no improvements existed in these categories for Raymond.

Table 4: Environmental Benefits of Soil Bioengineering				
	CHELAN		FORKS	
	Life Cycle Benefit	Annualized Benefit	Life Cycle Benefit	Annualized Benefit
Total Benefit:	$70,213	$1,404	$49,635	$993
Runoff Control	$2,730	$55	$44,460	$889
Air Pollutant Uptake	$59,305	$1,186	$962	$19
CO_2 Sequestration	$8,178	$164	$4,213	$84

This table shows that there are substantial environmental benefits from using the soil bioengineering approach. The benefits vary depending on site conditions, but do contribute to the overall picture. If other environmental benefits, such as visual, aesthetic, or species recovery benefits, would be included, then these values would be higher.

Environmental benefits will be achieved using the soil bioengineering method and account for part of the total project benefits.

Benefit/Cost Ratio

The benefit to cost ratio is a means of comparing the dollar figure of total benefits derived in relation to the cost of a project. In order to determine the degree of benefits, the following table was produced to illustrate the benefit – cost ratio for each option as well as each site: (Note that these figures include the annualized maintenance cost savings.)

Table 5: Benefit - Cost Ratio			
	CHELAN	RAYMOND	FORKS
Soil Bioengineering	1.46	8.14	6.37
Traditional Approach	1.20	1.00	1.08

This table shows that for each dollar spent on a soil bioengineering project, $1.46 in benefits was generated at the Chelan site, $8.14 at the Raymond site and $6.37 at the Forks site. In general, compared with the traditional option, for each dollar invested in roadside stabilization, the soil bioengineering method generated more than the traditional method in benefits.

It is clear from this table that at the Raymond and Forks sites, the benefits of the soil bioengineering method substantially outweigh the costs. It is also important to note that the Chelan site showed an increase in benefits by including the environmental benefits into the equation and not solely relying on cost savings.

Thus, one is able to conclude that soil bioengineering is a viable alternative and has a higher benefit-cost ratio in relation to the traditional method at these sites.

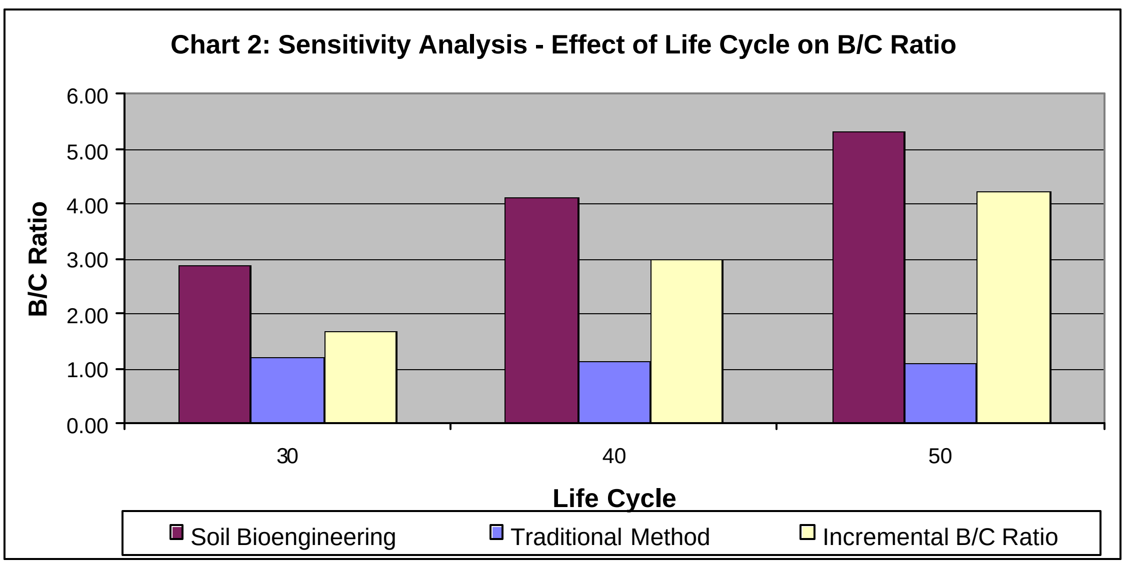
SENSITIVITY ANALYSIS

Sensitivity analysis is required because of uncertainty, risk and accuracy of estimations. Results for different values vary and are tested for the uncertain variables. This process may show how results of an analysis change when some of the assumptions on which the analysis is based are altered. The factors, which are most influential to the results, are established with the key determinants identified. For this study, these factors were:

- the effect of life cycle on cost savings
- the effect of the air pollutant uptake effectiveness value on the benefit – cost ratio
- the effect of discount rate on the benefit - cost ratio

Life Cycle

The first factor, life cycle, was compared at 30, 40 and 50 years to determine whether a different value would have any effect on the results of the analysis. Literature and professionals confirm that the life cycle of soil bioengineering is at least 50 years, so this value was used in the study.[15] The sensitivity test shows how the benefit – cost ratio changes if lower life cycles had been used.

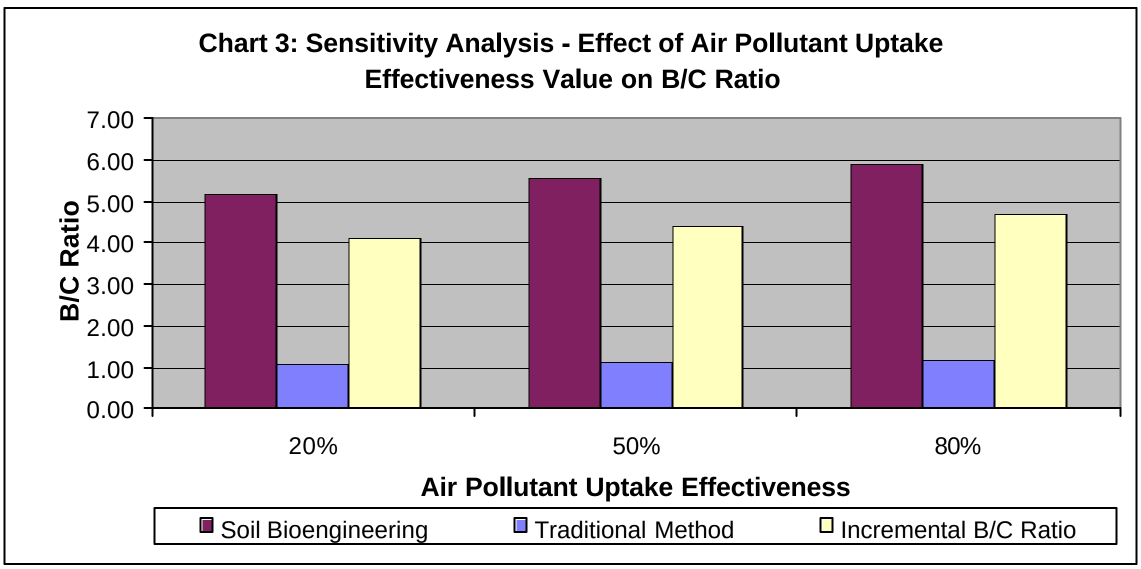


[15] Sotir, Robbin. Personal Communication 2000.
Schiechtl, H.M. and R. Stern. 1997. *Ground Bioengineering Techniques for Slope Protection and Erosion Control.* Blackwell Science Publications. ISBN: 0-632-04061-0.

The chart shows that the cost savings increases for the soil bioengineering project based on the increased life of the project. This is partially due to the fact that it is a living, self-repairing system and the mechanical stabilization and environmental benefits would increase as the vegetation matures. Also, the cost of soil bioengineering decreases as the life cycle increases because initial investment costs can be higher but with a longer life cycle, those costs would have less impact. The traditional method shows no change in value as life cycle increases. Therefore, the longer the life cycle of the soil bioengineering approach, the better the economic efficiency.

Air Pollutant Uptake Effectiveness

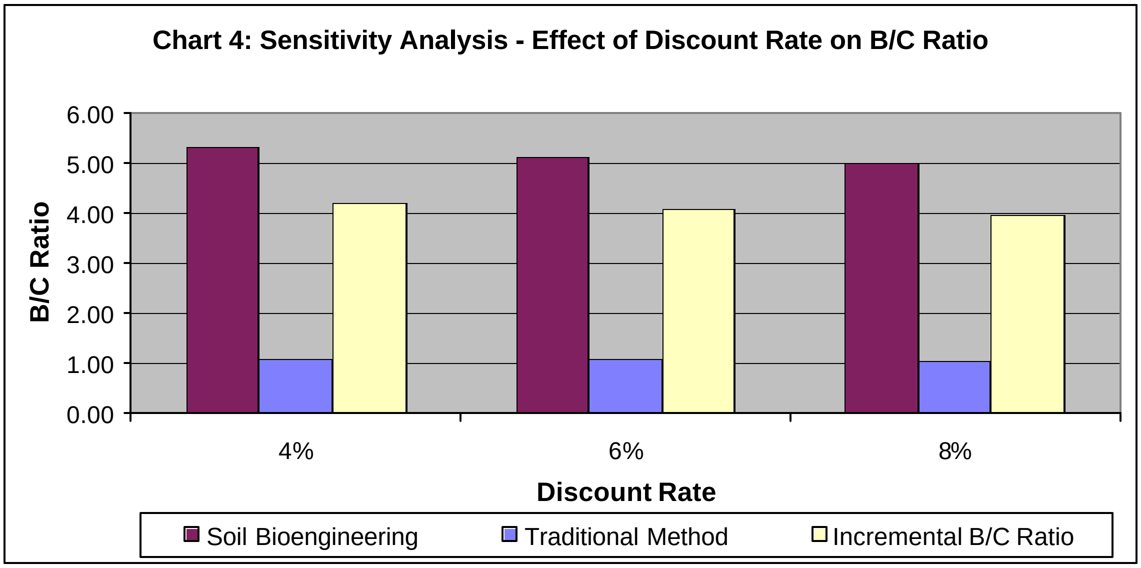
The second factor, the air pollutant uptake effectiveness value, was compared at 20%, 50% and 80% effectiveness to determine whether this factor had any effect on the results.



The relationship of these assumptions to the incremental benefit - cost ratio was evaluated. The chart shows that as a higher effectiveness percentage is used, the benefit – cost ratio increases slightly. The differences between the two methods change, going from 5.18 to 5.91 for the soil bioengineering approach while only changing from 1.07 to 1.19 with the traditional approach. Therefore, as more air pollutants are taken up by the living material integrated in soil bioengineering, the better the economic efficiency. This suggests that a soil bioengineering project would be more beneficial in urban and industrial areas than rural areas because the pollution in urban areas is usually much higher.

Discount Rate

The final factor, the discount rate, was compared at 4%, 6%, and 8%, again to determine whether this factor had any effect on the results of the analysis.



The relationship of the rate assumption to the incremental benefit - cost ratio was evaluated. This chart shows a slight decline in the benefit – cost ratio as a higher discount rate is used for soil bioengineering. There is not much change in the incremental benefit – cost ratio. Therefore, a lower discount rate will show favoritism towards the soil bioengineering approach, but the discounting effects are not robust unless environmental benefits significantly outweigh the cost savings benefit. This is because the discount rate does not affect cost savings, which is a large part of the total achieved benefit in this study.

The sensitivity analysis shows that there is greater economic efficiency when a longer life cycle is used and as air pollutant uptake effectiveness increases as vegetation matures with the soil bioengineering method. Discounting effects, however, are not noticeable unless environmental benefits significantly outweigh the influence of the cost savings benefit.

SUMMARY AND CONCLUSION

Investigating alternative approaches to traditional methods is a progressive way to move into the future. Road construction and maintenance impacts the Washington State Department of Transportation significantly. If new methods are shown to be viable, the rewards reaped by their implementation can benefit many.

While this study was limited to only three sites, it was able to offer further evidence to some of the benefits of employing soil bioengineering as an alternative for typical roadside management problems from a benefit - cost angle. The following points were derived from the analysis:

- Based on life cycle analysis, all three projects achieved savings in costs by using the soil bioengineering method.
- While cost savings is the most substantial benefit for the sites, environmental benefits are also significant.
- For every dollar invested in roadside stabilization, the soil bioengineering method generated more in benefits than the traditional method.
- Soil bioengineering will more likely be efficient when a traditional method requires a lump sum investment.
- The longer the life cycle of the soil bioengineering method, the better the economic efficiency.
- As the uptake effectiveness increases, the benefits of soil bioengineering versus the traditional method increase.
- A lower discount rate will be in favor of soil bioengineering projects but the discounting effects are not strongly evident unless environmental benefits significantly outweigh the cost saving benefit.
- The environmental benefits associated with soil bioengineering methods are likely to be more significant in urban and industrial areas rather than rural areas due mainly to air quality and reduction in runoff.
- When traditional methods trigger environmental compliance requirements, soil bioengineering projects are likely to be better candidates.

This study is limited by the number of sites evaluated. The contributors suggest that costs of future soil bioengineering projects should be recorded along with the costs of the most likely technical fix. Then, a cost – benefit analysis could be done when a statistically adequate number of projects are completed in order to further enhance our knowledge. In addition, future research should include an effectiveness test that could be preformed by installing two treatments side-by-side and testing for actual performance.

Despite these limitations, successes have been achieved. All three project sites are stabilizing erosion problems. At this time, there is 48% ground cover at Chelan, 98% at Forks and 90% at Raymond. Though this study did not analyze aesthetic benefits, they are an additional benefit of soil bioengineering methods. All sites will be monitored over time and long-term effects will be reported after the monitoring is completed. Though this method may not apply to all sites, it is a viable alternative tool for WSDOT road managers. Future research at sites with various climate and soil regimes will contribute to the knowledge gained with this study.

Sediment contamination of watersheds is one factor that is being addressed in salmon recovery efforts. Almost every county in Washington is being impacted by these efforts. As a government agency, directly accountable to the citizens of this state, it is important to take a lead in watershed projects, especially when techniques are cost efficient, use locally available material, have substantial environmental benefits, and are easy to install.

This study has shown that when technically feasible, soil bioengineering approaches can be adopted to produce equal or better economic and environmental results compared to the traditional geotechnical and hydraulic solutions alone. Both from a cost comparison and an environmental benefit analysis, it has been shown to be a viable economic alternative in roadside management.

CITED REFERENCES

California State Department of Transportation (CDOT). 1998. *Cost of Stormwater Treatment for California Urbanized Areas.*

Dowling Associates, Inc., et.al. 2000. *WSDOT Mobility Project Prioritization Process: B/C Software User's Guide.* Oakland, California

Gray, Donald and Robbin Sotir. 1995. Biotechnical Stabilization of Steepened Slopes. Prepared for the Transportation Research Board 74th Annual Meeting. Washington, D.C., January 22-28.

King, Dennis and Marisa Mazzotta. 2001. *Ecosystem Valuation*. Funded by USDA, NRCS, and NOAA. Accessed at: http://www.ecosystemvaluation.org.

Lewis, Elizabeth, soil scientist. 2000. Personal Communication July 7 and August 24. United States Forest Service, National Riparian Service Team.

Lewis, Elizabeth, Shannon Hagen, Mark Maurer, and Sandy Salisbury. 2000. Washington DOT Investigates the Soil Bioengineering Alternative. *Public Works Magazine,* August, 42-44.

Lewis, L. 2000. Soil Bioengineering An Alternative for Roadside Management: A Practical Guide. *USDA Forest Service, Technology & Development Program.* 7700-Transportation Management. 0077 1801—SDTDC.

Lewis, Lisa, Sandra Salisbury, Shannon Hagen and Mark Maurer. 2001. Soil Bioengineering for Upland Slope Stabilization. *Washington State Department of Transportation.* WA-RD 491.1. April.

Moses, Lynn, senior engineering geologist. 2000. Personal Communication August 24. Washington State Department of Transportation, Materials Laboratory.

McPherson, Gregory E., James R. Simpson, Paula J. Peper, and Qingfu Xiao. 1999. Benefit-Cost Analysis of Modesto's Municipal Urban Forest. *Journal of Arboriculture,* 25 no. 5: 235-248.

Nordstrom, Donald, maintenance supervisor. 2000. Personal Communication June 15. Washington State Department of Transportation, Olympic Region, Forks.

Salisbury, Sandra. 2000. Personal communication. Washington State Department of Transportation, Design Office.

Schiechtl, H.M. and R. Stern. 1997. *Ground Bioengineering Techniques for Slope Protection and Erosion Control.* Blackwell Science Publications. ISBN: 0-632-04061-0.

Sotir, R.B. and Christopher, B.R. 2000. Soil Bioengineering and Geosynthetics for Slope Stabilization and Soil Bioengineering and Geosynthetics for Slope and Streambank Stabilization – Case Histories. *Geosynthetics 2000 Conference.* Kuala Lumpur, Malaysia.

Sotir, R.B. 2001. *The value of vegetation – Strategies for implementing soil bioengineering into civil engineering projects;* Soil Bioengineering Conference – Integrating Ecology with Engineering Practice. Birmingham, England.

Sotir, Robbin. 1998. "Brushing up on erosion control." *American City and County*. February: 18-25.

Sotir, Robbin, president. Robbin B. Sotir & Associates, Inc. 2000. Personal communication January 22.

Sotir, Robbin, president. Robbin B. Sotir & Associates, Inc. 2001. Personal communication June.

Tveten, Richard K. statewide erosion control coordinator. 2000. Personal communication July 5. Washington State Department of Transportation, Olympia Service Center.

U.S. Environmental Protection Agency (EPA). 1999. *Economic Analysis of the Final Phase II Stormwater Rule*. Prepared by the Office of Water. EPA 833-R-99-002.

U.S. Environmental Protection Agency (EPA). 2000. *Guidelines for Preparing Economic Analysis.* Prepared by the National Center for Environmental Economics. Available online at http://www.epa.gov/economics/

Washington State Department of Transportation. 1995. *Highway Runoff Manual*. 16 February, WA-M31-, p.1-5.

Witecki, Matt, state hydraulics engineer. 2000. Personal communication, July 3. Washington State Department of Transportation, Olympia Service Center.

Xu, George. 2000. *Stormwater Benefit Cost Progress Report*. Washington State Department of Transportation. Olympia, Washington.

REFERENCES CONSULTED

Anderson, Darrell, maintenance analyst. 2000. Personal Communication, July 5. Washington State Department of Transportation, North Central Region.

Bowen, Bert D., senior water quality specialist. 2000. Personal Communication, June 1. Washington State Department of Transportation, Environmental Affairs Office.

California State Department of Transportation (CDOT). 1999. *Highway Design Manual - Hydrology*. CH 810, topic 819.2 (1).

Clarke, J., forester. 2000. Faxed information sheet, and telephone conversation with Shannon Hagen, July 6. Rayonier Timber Company, Northwest Forest Resources, Clallam Office.

Cornell University, Crop and Soil Sciences Department. *Why Soils Differ*. Lecture 3, Unit 1/Section 1, p.9.

Finney, Kevin, landscape architect. 1993. The Eleventh Annual California Salmonid Restoration Federation Conference in Eureka, California, March 20.

Gray, D.H. and Sotir, R. 1996. *Biotechnical and Soil Bioengineering Slope Stabilization.* John Wiley & Sons: New York, New York.

Hicks, B. J., J. D. Hall, P. A. Bisson and J. R. Sedell. 1991. Responses of salmonids to habitat changes. Influences of forest and rangeland management on salmonid fishes and their habitats. *American Fisheries Society Special Publication* 19: 483-518.

Moses, Lynn, senior engineering geologist. 1999. Personal Communication July 13. Washington State Department of Transportation, Materials Laboratory.

Myrum, Ron, district conservationist. 2000. Personal Communication July 29. United States Department of Agriculture, Natural Resources Conservation Service, Wenatchee Field Office.

Perkins, Cerry, district conservationist. 2000. Personal Communication June 19. United States Department of Agriculture, Natural Resources Conservation Service.

Phillips, R. W., R. L. Lantz, E. W. Claire and J. R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. *Transactions of the American Fisheries Society* 3: 461-466.

Shaw, Larry, reforestation specialist. 2000. Personal Communication July 7. United States Forest Service, Wenatchee National Forest.

Skinner, Jim, Lost Creek realignment project engineer. 2000. Personal communication June 20. Washington State Department of Transportation, Olympic Region.

Steele, Alan, maintenance supervisor. 2000. Personal communication June 20. Washington State Department of Transportation, North Central Region.

Tate, Kenneth W. *Rangeland Watershed Program - Fact Sheet No. 37*. Department of Agronomy & Range Science, University of California, Davis, CA 95616-8515

University of Missouri. 1999. *Fugitive Dust: Non-point Sources.* Columbia: University of Missouri, October 31, p.2.

U.S. Department of Agriculture Soil Conservation Service. 1992. Chapter 18: *Soil Bioengineering for Upland Slope Protection and Erosion Reduction.* Part 650, 210-EFH, Engineering Field Handbook, 53 pp.

Washington State Department of Fish and Wildlife. 1997. *The Watershed Recovery Inventory Project, First Draft Report.* November, p.1-15.

Washington State Department of Transportation. 2000. *Soil Bioengineering for Slopes.* August, WA-RD9227.

Washington State Department of Transportation. *Construction Site Erosion & Spill Control Certification Course.* WSDOT/EAO/RT/Sec 2.3.6

Soil Bioengineering Appendix

APPENDIX 1: BASIC CONCEPTS, HISTORY AND
ADVANTAGES & LIMITATIONS OF SOIL BIOENGINERRING

APPENDIX 2: CONSTRUCTION DETAILS OF THE THREE CHOSEN SITES

APPENDIX 3: COSTS

APPENDIX 4: METHODOLOGY OF BENEFIT ASSESSMENT

APPENDIX 5: BENEFITS

APPENDIX 6: BENEFITS TRANSFER SUMMARY

APPENDIX 1

Basic Concepts, History, and Advantages and Limitations of Soil Bioengineering[16]

[16] Adapted from Lewis, L. 2000. Soil Bioengineering An Alternative for Roadside Management: A Practical Guide. *USDA Forest Service, Technology & Development Program*. 7700- Transportation Management. 0077 1801-SDTDC.

Basic Concepts

Soil bioengineering projects require more than simple site evaluation and measurement. In fact, they require a more sophisticated and comprehensive approach to land management, which results in greater and broader benefits and functions.[17] The natural history and evolution in the area along with cultural and social uses need to be considered in the design. Some areas of evaluation include: climatic conditions, watershed alteration, topography and aspect, soils, water, vegetation and the erosion process. The goals of land management for the present and future are also important to consider and help determine the project's potential and capability.

Trends at erosion sites are key to understanding the landscape. Whenever erosion occurs, whether naturally or through human intervention, the site immediately begins to self-heal. First, the slope adjusts, allowing vegetation to establish once an angle of repose is established. Shrubs and trees may follow along this line of succession. Therefore, it is important to examine and understand these natural trends. The basic concept of soil bioengineering is to accelerate site recovery by mimicking or accelerating what would happen naturally.

Some soil bioengineering implementation techniques include:

- Native plant cuttings and seed collection
- Salvaging and transplanting native plants
- Planting containerized and bare root plants
- Distribution of seed, fertilizer and certified noxious weed-free straw or hay
- Live staking
- Installation of erosion control blanket
- Construction of live cribwalls
- Live fascines
- Brushlayering
- Willow fencing modified with brushlayering
- Branchpacking
- Live gully repair
- Vegetated geotextile
- Log terracing

A single technique or multiple techniques can be applied at a project site. Whatever is chosen, is highly dependant on site conditions.

History of Soil Bioengineering

Early techniques of using live plants to solve engineering problems can be traced back to Asia and Europe. As early as 28 BC, dike repair in China included using

[17] Sotir, Robbin. Personal Communication 2001.

large baskets woven of willow, hemp, or bamboo that were filled with rocks to stabilize slopes. In Europe, willow branches were woven together to create fences and walls. Romans used fascines, bundles of willow poles, for hydroconstruction.

Refined techniques were used throughout Europe by the 16th Century. Live stakes were used for vegetation and stabilizing streambanks. Rows of brushy cuttings were planted in waterways for trapping sediment and reshaping channels. As the mountainous areas of Austria and southern Germany were extensively logged over the next several centuries, soil bioengineering techniques were continuously evolving to alleviate problems associated with logging. Foresters and engineers studied traditional techniques, adapted their practices, and published their work. Construction of the German Autobahn involved extensive applications of soil bioengineering technologies.

In the U.S., early work in this field began around the 1930's. Charles Kraebel, working in California for the U.S. Department of Agriculture (USDA) Forest Service, developed his "contour wattling" techniques for stabilizing road cuts. He used live stakes, live fascines and vegetative transplants to stabilize degrading slopes in the National Forests of central and southern California. The Natural Resource Conservation Service (NCRS) began a study of bluff stabilization techniques along the shores of Lake Michigan and published the results in 1938.

In the 50's and 60's, German and Austrian soil bioengineers continued to perfect their techniques and published their work. In the 70's and 80's, two important projects in the U.S., in California, were well-documented and provided important information to further boost the field.

Solid establishment of soil bioengineering in the English-speaking world came with a Canadian English publication in 1980 of Hugo Schiechtl's *Bioengineering for Land Reclamation and Conservation*. This document allowed for a vast amount of technological and historical information to be accessible to an audience that had previously been limited by language barriers. Soil bioengineering became fully established across the globe.

However, despite the many publications since then, there is still resistance to the technology and a continual need to prove the benefits of soil bioengineering. Fortunately, increasing environmental consciousness from the public, often makes soil bioengineering solutions more acceptable than traditional "hard" engineering approaches because it tends to be less invasive, is compatible with the natural surroundings, uses local materials and minimizes the use of heavy equipment. Additionally, the fact that soil bioengineering is always based on sound engineering has offered a better understanding and thus received a better response from the engineering community.[18] The long history associated with this technology contributes to its' validity, and future need for development.

[18] Sotir, Robbin. 2001. Personal Communication.

Advantages:

Projects usually require less heavy equipment excavation. As a result, there is less cost and less site impact. In addition, limiting hand crews to one entrance and exit route will cause less soil disturbance to the site and adjoining areas.

Erosion areas often begin small and eventually expand to a size requiring costly traditional engineering solutions. Installation of soil bioengineered systems while the site problem is small will provide economic savings and minimize potential impacts to the road and adjoining resources.

Soil bioengineering systems offer immediate erosion control and soil reinforcement. Over time, they further provide improved face stability through mechanical reinforcement by roots.[19]

Use of native plant materials and seed may provide additional savings. Costs are limited to labor for harvesting, handling and transport to the project site. Indigenous plant species are usually readily available and well adapted to local climate and soil conditions.

Soil bioengineering projects may be installed during the dormant season of fall, winter, and early spring. This is the best time to install soil bioengineered work and it often coincides with times when other construction work is slow.

Soil bioengineering work is often useful on sensitive or steep sites where heavy machinery is not feasible.

Years of monitoring has demonstrated that soil bioengineering systems are strong initially and grow stronger with time as vegetation becomes established. Even if the plants do not establish or later die, the installed technique will function mechanically. Roots and surface organic litter will continue to play an important mechanical role during reestablishment of other plants.

Once plants are established, root systems reinforce the soil mantel and remove excess moisture from the soil profile. Modifications of soil moisture regimes occur through improved drainage and depletion of soil moisture along with the increase of soil suction by root uptake and transpiration. This often is the key to long-term soil stability.[20]

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[19] Sotir, R.B. and Christopher, B.R. 2000. Soil Bioengineering and Geosysnthetics for Slope Stabilization. *Geosynthetics 2000 Conference.* Kuala Lumpur, Malaysia.

[20] Sotir, R.B. 2001. *The value of vegetation – Strategies for implementing soil bioengineering into civil engineering projects;* Soil Bioengineering Conference – Integrating Ecology with Engineering Practice. Birmingham, England.

Soil bioengineering is typically acceptable and permitable by regulatory agencies.

Soil bioengineering provides improved visual and habitat values.

Limitations:

Soil bioengineering should not be viewed as the sole solution to erosion and slope stability problems. Soil bioengineering represents one important element. It has unique requirements and is not appropriate for all sites and situations. On certain surface erosion areas, for example, distribution of grass and forb seed mixes, hydromulching, or spreading of a protective layer of weed-free straw may be satisfactory and less costly than more extensive bioengineering treatments.

On areas of potential or existing mass wasting, soil bioengineering may need to be integrated with a variety of geotechnically-engineered systems.

On highly erosive sites, maintenance of the combined system will be needed until plants have established. Established vegetation can be vulnerable to drought, fire, soil nutrient and sunlight deficiencies, road maintenance sidecast debris, grazing, or trampling, and may require special management measures to ensure longterm project success.

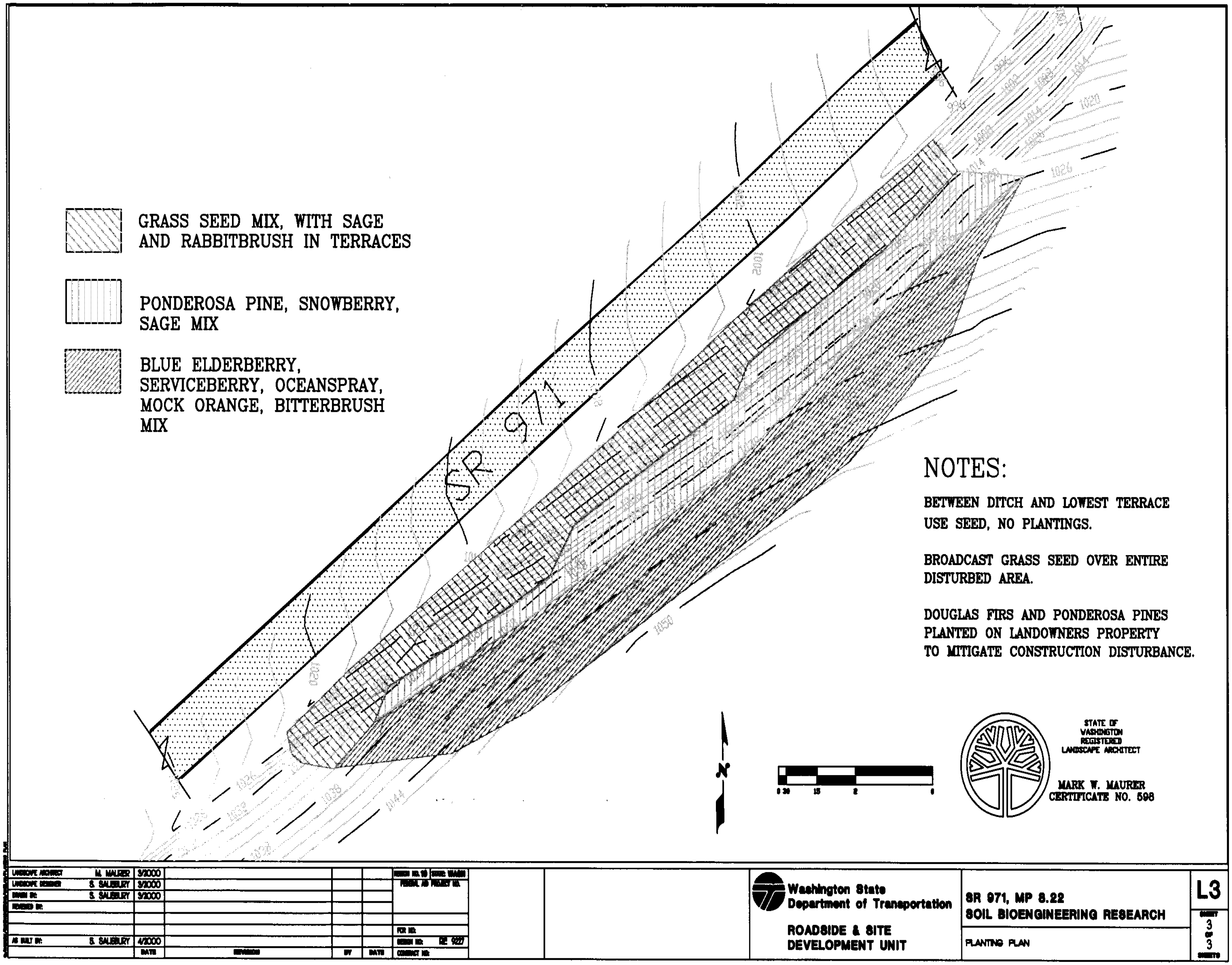
Soil bioengineering projects tend to require more planning time than conventional engineering projects.

Soil bioengineering projects are most successful and least expensive when installed during the dormant season, which may not coincide with a particular construction project repair needs and, in Washington State, coincides with the rain and snow season.

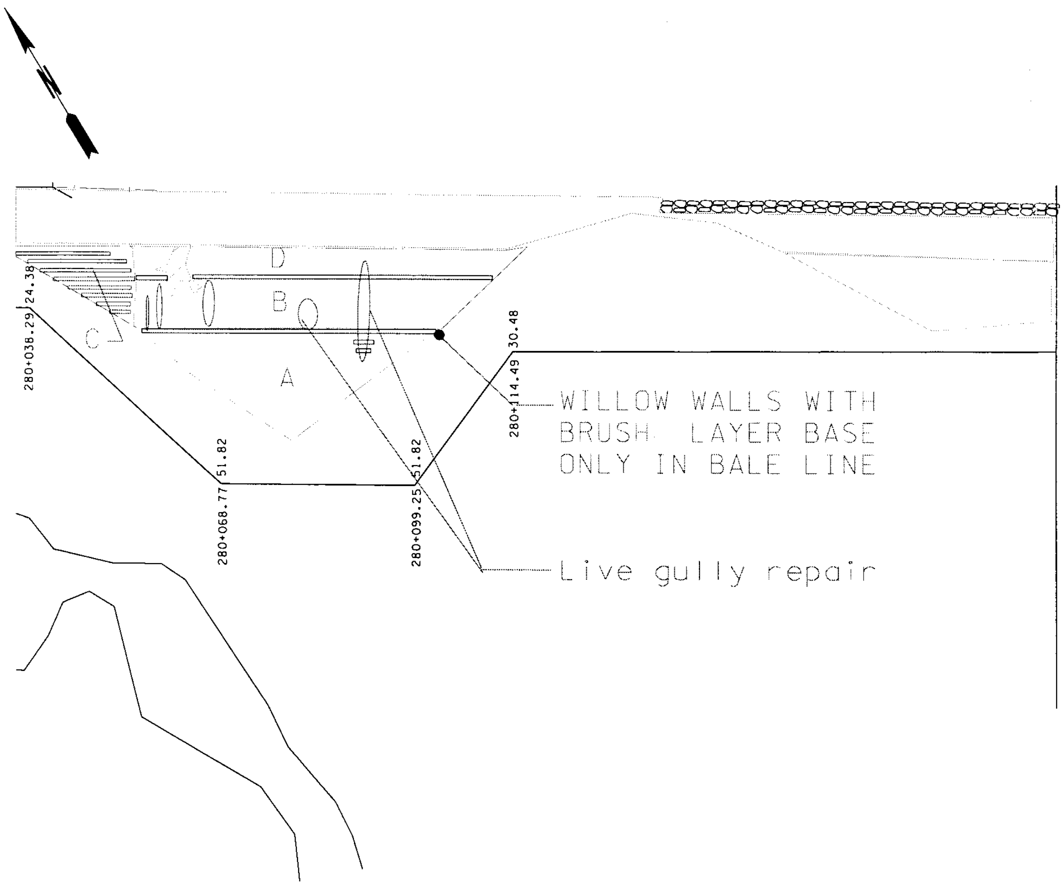
Appendix 2

Construction details of the three chosen sites[21]

[21] Additional details can be found in the document: Soil Bioengineering for Upland Slope Stabilization. Authored by: Lisa Lewis, Sandra Salisbury, Shannon Hagen and Mark Maurer. *Washington State Department of Transportation.* WA-RD 491.1. April 2001.


GRASS SEED MIX, WITH SAGE AND RABBITBRUSH IN TERRACES
PONDEROSA PINE, SNOWBERRY, SAGE MIX
BLUE ELDERBERRY, SERVICEBERRY, OCEANSPRAY, MOCK ORANGE, BITTERBRUSH MIX
SR 971
NOTES:
BETWEEN DITCH AND LOWEST TERRACE USE SEED, NO PLANTINGS.
BROADCAST GRASS SEED OVER ENTIRE DISTURBED AREA.
DOUGLAS FIRS AND PONDEROSA PINES PLANTED ON LANDOWNERS PROPERTY TO MITIGATE CONSTRUCTION DISTURBANCE.
N
STATE OF WASHINGTON REGISTERED LANDSCAPE ARCHITECT
MARK W. MAURER
CERTIFICATE NO. 598
M. MAURER 3/2000
S. SALISBURY 3/2000
S. SALISBURY 3/2000
S. SALISBURY 4/2000
DATE
BY
DATE
Washington State Department of Transportation
ROADSIDE & SITE DEVELOPMENT UNIT
SR 971, MP 8.22
SOIL BIOENGINEERING RESEARCH
PLANTING PLAN
L3
3 OF 3

Forks/Lost Creek



Mix D	%Mix	# plants
Alnus crispa (Sitka Alder)	3	16.5
Oemleria cerasiformis (Indian-plum)	5	27.5
Mahonia nervosa (Oregon Grape)	6	33
Cornus sericea (Red-osier Dogwood)	14	77
Rubus spectabilis (Salmonberry)	12	66
Amelanchier alnifolia (Serviceberry)	12	66
Salix sitchensis (Sitka Willow)	14	77
Symphoricarpos alba (Snowberry)	12	66
Rubus parviflorus (Thimbleberry)	12	66
Rhamnus purshiana (Cascara)	4	22
Rosa nootkana (Nootka Rose)	4	22
Physocarpus capitatus (Pacific Ninebark)	2	11
Totals	100	550
Mix B	**%Mix**	**# plants**
Alnus crispa (Sitka Alder)	18	99
Oemleria cerasiformis (Indian-plum)	5	27.5
Mahonia nervosa (Oregon Grape)	5	27.5
Cornus sericea (Red-osier Dogwood)	7	38.5
Rubus spectabilis (Salmonberry)	9	49.5
Amelanchier alnifolia (Serviceberry)	4	22
Salix sitchensis (Sitka Willow)	4	22
Symphoricarpos alba (Snowberry)	23	126.5
Rubus parviflorus (Thimbleberry)	4	22
Rhamnus purshiana (Cascara)	4	22
Rosa nootkana (Nootka Rose)	3	16.5
Totals	86	473
MIX A	**%Mix**	**# plants**
Thuja plicata (Western Red Cedar)	25	15
Pseudotsuga menziesii (Douglas Fir)	25	15
Tsuga heterophylla (Western Hemlock)	25	15
Picea sitchensis (Sitka Spruce)	25	15
Totals	100	60
		# plants
TOTALS		1083

DESIGNED BY	L. LEWIS	8/25/99
ENTERED BY	S. HAGEN	8/25/99
CHECKED BY	L. LEWIS	8/25/99
PROJ. ENGR.	HART	
REGIONAL ADM.	DEMICH	

REGION	STATE
10	WASH
JOB NUMBER	
CONTRACT NO.	

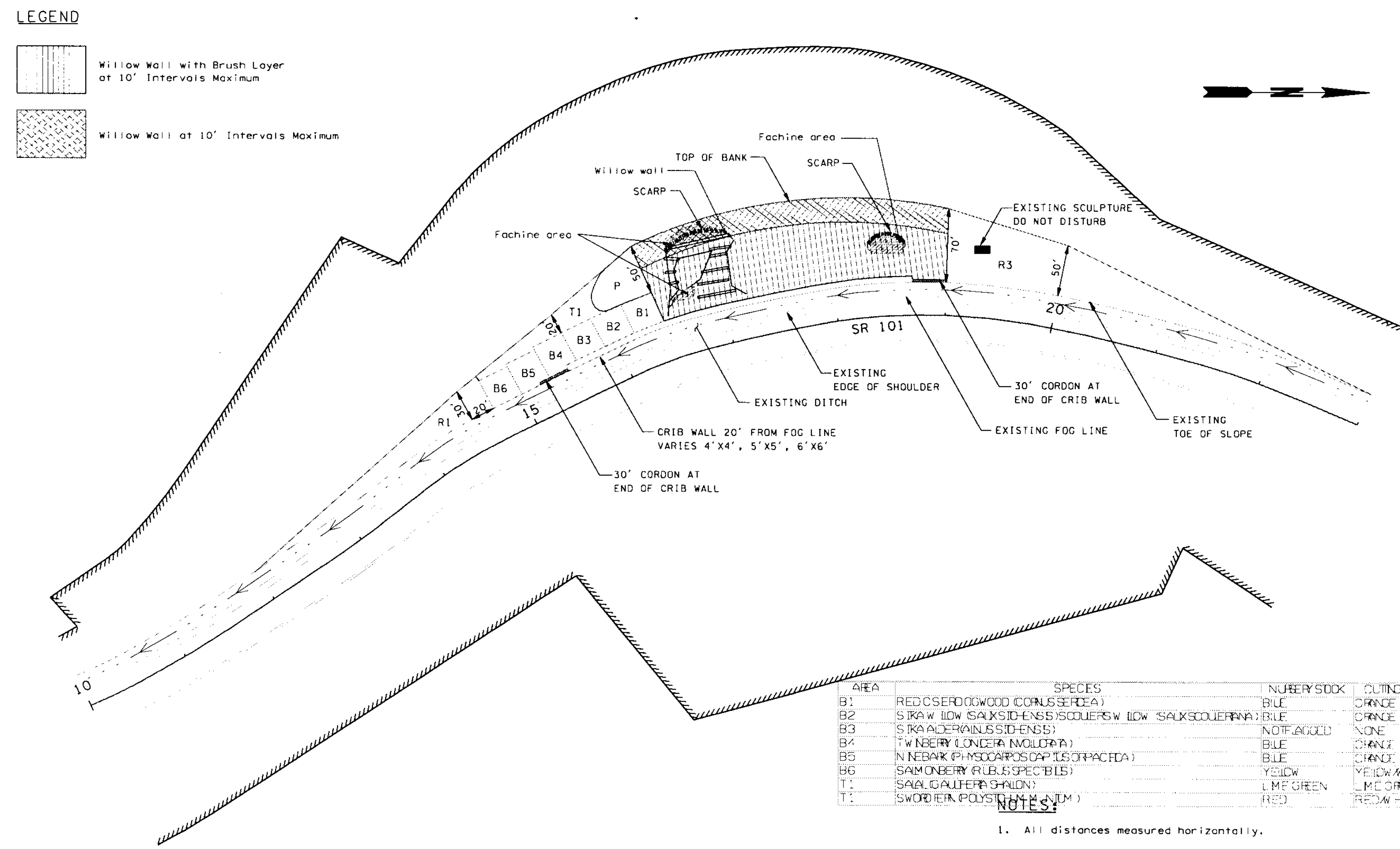
PROJECT DEVELOPMENT OFFICE

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

LOST CREEK SLIDE

BIOENGINEERING

SHEET OF SHEETS



AREA	SPECIES	NURSERY STOCK	CUTTINGS/TRANSPLANT
B1	RED OSIER DOGWOOD (CORNUS SERICEA)	BLUE	ORANGE
B2	SITKA WILLOW (SALIX SITCHENSIS) SCOULERS WILLOW (SALIX SCOULERIANA)	BLUE	ORANGE
B3	SITKA ALDER (ALNUS SITCHENSIS)	NOT FLAGGED	NONE
B4	TWINBERRY (LONICERA INVOLUCRATA)	BLUE	ORANGE
B5	NINEBARK (PHYSOCARPOS CAPITUS OR PACIFICA)	BLUE	ORANGE
B6	SALMONBERRY (RUBUS SPECTABILIS)	YELLOW	YELLOW/WHITE
T1	SALAL (GAULTHERIA SHALLON)	LIME GREEN	LIME GRN/WHITE
T1	SWORD FERN (POLYSTICHUM MUNITUM)	RED	RED/WHITE

NOTES:

1. All distances measured horizontally.
2. This plan for informational purposes only. All work to be staked in field.
3. Plant spacing to be set in the field.

0 50 100
SCALE IN FEET

IGNED BY L. LEWIS	1/2000			
ERED BY B. WYMAN	1/2000			
CKED BY D. CORLETT	1/2000			
J. ENGR. D. RODIN				
. ADM. D. WAGNER				
	DATE	DATE	REVISION	BY

FORM 221-012

REGION NO.	STATE	FED. AID PROJ. NO.
10	WASH	
JOB NUMBER		
CONTRACT NO.		

ENVIRONMENTAL AND ENGINEERING SERVICE CENTER

Washington State Department of Transportation

$$$$$DESIGNFILENAME$$$$$

SR 101
RAYMOND VICINITY

SOUTHWEST REGION BIOENGINEERING DEMONSTRATION PROJECT

REFERENCE SHEET NUMBER

SHEET

OF

SHEETS

Soil Bioengineering Treatments

Chelan

The slope was reshaped to a 1.5H:1V slope to eliminate a vertical lip at the top.

1,875 feet of bender board fencing wall was constructed, terracing the slope to stop the chronic surface erosion and to establish "planting platforms". (These walls are similar to the Raymond site's willow walls, but substituting cedar bender board for the willow because of the arid climate.)

* 3,510 plugs of native vegetation (11 different species) were planted in the terraces behind each bender board wall, supplemented by 80 lbs of grass and native seeds.

27 cubic yards of compost was blown in place to enrich the soils.

Forks/Lost Creek

2700 square feet of rock apron was installed to mitigate surface erosion and stabilize the base of the slope.

A total of 414 linear feet of willow wall, with a brushlayer base, was constructed across the slope to spread the water out, slow it down, and prevent if from funneling through the gullies. After the willow walls were complete, the gullies were repaired packing with drain rock, soil, and willow stems.

18 different species of native vegetation (1083 plants total) were planted in the terraces and on the slope, supplemented by 16 lbs of grass and native seed.

Raymond

A 210 foot long live cribwall was constructed to stabilize the base of the slope, 150 feet of which measured 6 feet wide and 6.5 feet tall, with over 2,000 willow stems layered inside.

Over 100 feet of willow walls were constructed in areas where previous earth movement left sections over-steepened and vulnerable to surface erosion.

145 feet of live fascines were constructed to prevent surface erosion.

1,300 native plants were installed to reinforce the soil mantle, thus providing long-term site stability, supplemented by 50 lbs of grass seed for surface erosion protection.[22]

[22] Lewis, Elizabeth, et. al. 2000. Washington DOT Investigates the Soil Bioengineering Alternative. *Public Works Magazine.* August. 42-44.

Hypothetical Traditional Treatments

Chelan Site

The suggested traditional engineering treatment would have been to excavate the slope back to a 1.5H to 1V angle.[23] In addition, an application of a hydroseed mix with tackifier to control surface erosion was suggested.[24]

Forks/Lost Creek

The suggested traditional engineering treatment would have involved treating surface water runoff by collecting runoff at the base of the slope in a quarry spall-lined ditch, moving it under the road in a culvert, and into a detention pond to allow sedimentation.[25] The fine, compacted soils on the site resist infiltration leading to large amounts of overland flow, which contribute to sedimentation problems during and post road construction.[26] A rock apron was installed on this site to prevent slope movement prior to the research project. Its' cost is included in the estimated cost for the non-soil bioengineering treatment.

Raymond

The suggested traditional engineering treatment would have been to construct a rock buttress similar to the one directly across the highway from the project location. It should be noted that a soil stability analysis would be needed to determine the size (mass) of a rock buttress. The buttress would be keyed-in.[27] Without this study, the size of the proposed buttress was conservatively estimated to be the same as the volume of the constructed cribwall. It should also be noted that in this example, the purpose of the rock buttress is only to add a vertical component to the slope by which the toe of the slope is elevated to reduce overall steepness and to provide support for eroding materials. A bench would have to be excavated for placement of the rock buttress.

[23] Moses, Lynn. Personal Communication 2000.
[24] Salisbury, Sandra. Personal Communication 2000.
Tveten, Richard K. Personal Communication 2000.
[25] Salisbury, Sandra. Personal Communication 2000.
Witecki, Matt. Personal Communication 2000.
[26] Lewis, Elizabeth. Personal Communication 2000.
[27] Moses, Lynn. Personal Communication 2000.

Appendix 3

Costs

Table A1: Detailed Costs of Traditional Treatment: Chelan Site				
MAINTENANCE COSTS	**Unit**	**Units**	**$/unit**	**Total $**
Ditching, 3 pc. equip.	Day/Yr.	0.25	$880.00	$220.00
Annual Cost				$220.00
PV (LifeCycle)[28]				***$2,990***
COSTS W/TRADITIONAL TREATMENT				
Sediment Reduction	**Unit**	**Units**	**$/unit**	**Total $**
Hydroseed with tackifier and mulch	ACRE	0.5	$2,350.00	$1,175.00
Excavator (4.5days) Bulldozer (1day)	EA	1	$7,296.10	$7,296.10
Annual Rye grass seed	LB	20	$0.99	$19.80
Native Seed, custom mix	LB	66	$8.00	$528.00
Real Estate Services	EA	1	$500.00	$500.00
Survey Crews	DAY	1	$1,200.00	$1,200.00
Inspection	DAY	5	$246.40	$1,232.00
Per Diem	DAY	5	$100.00	$500.00
Traffic Control : Vehicle	DAY	6	$35.00	$192.50
Traffic Control : Labor (2 people)	DAY/2 Em	5.5	$448.00	$2,464.00
Traffic Control : Supervisor	DAY	5.5	$240.00	$1,320.00
Roadside Clean - Up	EA	1	$500.00	$500.00
Total Sediment Reduction Cost (PV)				***$16,927.40***
Subtotals				
Roadside planting and erosion control				$547.80
Personnel				$7,216.00
Excavation/Heavy Equipment				$7,296.10
Maintenance				$2,989.87
Subtotal Cost (PV)				***$19,917.27***
Mobilization Cost				*$1,991.73*
Total Cost (PV) (including 6% sales tax)				***$23,223.54***

Note: Mobilization costs (pre-project set up expenses) and sales tax were added on to the hypothetical traditional treatment costs in order to make the total cost comparable to the soil bioengineering treatment total costs.

[28] PV = Present Value. In order to make costs comparable at one point in time, the costs are discounted and then totaled.

Table A2: Detailed Costs of Soil Bioengineering Treatment: Chelan Site

MATERIALS	**Unit**	**Units**		**$/unit**		**Total $**
Spray paint	EA	2	$	1.11	$	2.22
Flagging Tape	EA	7	$	1.89	$	13.23
Rebar 1/2" x 20'	EA	93	$	3.13	$	291.09
Straw bales	EA	11	$	5.50	$	60.50
Annual Rye grass seed	LB	20	$	0.99	$	19.80
Rebar 1/2" x 20'	EA	132	$	3.13	$	413.16
Wood Stakes 1/2" x 24" (50/bd)	BD	35	$	7.88	$	275.80
Compost, GroCo	CU YD	30	$	26.00	$	780.00
Trucking Mileage	MI	183	$	3.00	$	549.00
Rebar 1/2" x 20'	EA	20	$	3.35	$	67.00
Native Seed, custom mix	LB	66	$	8.00	$	528.00
Bender Board, Cedar	LF	24000	$	0.10	$	2,400.00
Wooden Stakes 2"x2"x4'	BD	21	$	16.45	$	345.45
Twine, garden 150'	EA	1	$	2.84	$	2.84
Hacksaw Blades 12x24	EA	1	$	1.89	$	1.89
Hacksaws	EA	2	$	5.49	$	10.98
Hacksaw Blades 12x24	EA	4	$	2.29	$	9.16
Supplies Total					***$***	***5,770.12***
EQUIPMENT RENTALS	**Unit**	**Units**		**$/unit**		**Total $**
Partner Saw	DAY	1	$	42.00	$	42.00
Metal Blades	EA	1	$	9.92	$	9.92
Rentals Total					***$***	***51.92***
PLANT MATERIAL TOTAL*					***$***	***2,093.00***
OPERATION AND MAINTENANCE[29]					***$***	***5,232.50***
HEAVY EQUIPMENT	**Unit**	**Units**		**$/unit**		**Total $**
Excavator (4.5days) Bulldozer (1day)	***EA***	***1***	***$***	***7,296.10***	***$***	***7,296.10***
WSDOT PERSONNEL	Unit	Units		$/unit		Total $
Inspection	DAY	30.625	$	124.80	$	3,822.00
Real Estate Services	EA	1	$	500.00	$	500.00
Survey Crews	DAY	1	$	1,200.00	$	1,200.00
Per Diem**	EA	1	$	1,143.39	$	1,143.39
Personnel Total					***$***	***5,522.00***

[29] This includes approximately $1,500 that was used for repairing a small section of the slope that failed after a period of heavy rains on a snow layer. Approximately 40' of the total 1,875' failed.
Operation and maintenance costs for soil bioengineering generally are attributed to plant establishment.

Table A2 continued: Chelan

WCC CREW	**Unit**	**Units**		**$/unit**		**Total $**
WCC Total	***DAY***	***52.5***	***$***	***500.00***	***$***	***26,250.00***
TOTAL CHELAN COSTS					**$**	**52,215.64**
COSTS / SQ. FT.	**Unit**	**Units**		**Cost**		**Total $/Sq. Ft.**
TOTAL	**SQ FT**	**24000**	**$**	**52,215.64**	**$**	**2.18**

Note: Mobilization costs, sales tax and traffic control costs are included in all the soil bioengineering totals. They are hidden costs since actual costs were used in this analysis.

Table A3: Detailed Costs of Traditional Treatment: Raymond Site

MAINTENANCE COSTS	**Unit**	**Units**	**$/unit**	**Total $**
Ditching Raymond Maint.	DAYS/YR.	0.20	$2,100.00	$420.00
Annual Cost				$420.00
PV (LifeCycle)				***$5,707.94***
COSTS W/TRADITIONAL TREATMENT				
Stabilization	**Unit**	**Units**	**$/unit**	**Total $**
Bulldozer & Excavator (1pc./day)	DAY	12	$1,326.56	$15,918.72
Heavy Rip Rap	CU YD	2,073	$59.63	$123,612.99
Hydroseeding	SF	28,075	$0.05	$1,263.38
Inspection	DAY	10	$246.40	$2,464.00
Traffic Control : Vehicle	DAY	12	$55.00	$660.00
Traffic Control : Labor (2 people)	DAY/2 Em	12	$512.00	$6,144.00
Traffic Control : Supervisor	DAY	12	$256.00	$3,072.00
Roadside Clean - Up	EA	1	$500.00	$500.00
Total Stabilization Cost				***$153,635.09***
Subtotal Cost (PV)**				***$153,635.09***
Mobilization Cost				*$15,363.51*
Total Cost (PV) (including 6% sales tax)				***$179,138.51***

** Constructing the traditional treatment would eliminate maintenance needs.

Table A4: Detailed Costs of Soil Bioengineering Treatment: Raymond Site

MATERIALS	Unit	Units	$/unit	Total $
Flagging Tape	EA	4	$ 1.79	$ 7.16
Tape Measure	EA	1	$ 7.99	$ 7.99
Spray Paint	EA	1	$ 2.99	$ 2.99
Spray Paint (florescent)	EA	1	$ 4.99	$ 4.99
Drill bit extension 6"	EA	3	$ 4.29	$ 12.87
Drill bit extension 10"	EA	2	$ 5.49	$ 10.98
Drill bit extension 10"	EA	2	$ 6.89	$ 13.78
Drill bit (speedbor)	EA	1	$ 2.79	$ 2.79
Drill bit (speedbor spade)	EA	1	$ 3.59	$ 3.59
Drill bit (solid)	EA	2	$ 8.62	$ 17.24
Drill bit (solid)	EA	2	$ 8.29	$ 16.58
Auger bit	EA	1	$ 9.39	$ 9.39
Drill bit 15/16	EA	1	$ 3.49	$ 3.49
Ship Auger	EA	1	$ 24.99	$ 24.99
Nails	LB	2.25	$ 1.10	$ 2.48
Rebar 20'	EA	39	$ 3.49	$ 136.11
Flagging Tape	EA	1	$ 1.50	$ 1.50
Cable 3/8"	FT	100	$ 0.53	$ 53.00
Mag bit	EA	2	$ 30.00	$ 60.00
Hemlock Logs 40'	EA	72	$ 67.50	$ 4,860.00
Cable 3/8"	FT	50	$ 0.74	$ 37.00
Straw bales	EA	10	$ 4.00	$ 40.00
Annual Rye grass seed	LB	50	$ 0.39	$ 19.50
Cable 3/8"	FT	200	$ 0.97	$ 194.00
Cable clamps	EA	10	$ 0.42	$ 4.20
Misc		1	$ 9.38	$ 9.38
Supplies Total				***$ 5,556.00***
EQUIPMENT RENTALS	**Unit**	**Units**	**$/unit**	**Total $**
2 ea. Drills 1/2" gas powered	DAY	11	$ 33.12	$ 364.32
Drill 1/2" Hole Hawg	DAY	10	$ 9.55	$ 95.50
Rentals Total				***$ 459.82***
PLANT MATERIAL TOTAL*				***$ 1,800.50***
OPERATION & MAINTENANCE				***$ 4,501.25***
HEAVY EQUIPMENT	**Unit**	**Units**	**$/unit**	**Total $**
Bulldozer & Excavator (1pc./day)	DAY	5.5	$ 1,326.56	$ 7,296.08
Heavy Equipment Total				***$ 7,296.08***
WSDOT PERSONNEL	**Unit**	**Units**	**$/unit**	**Total $**
Inspection	***Day***	***33.75***	***$ 124.80***	***$ 4,212.00***

Table A4 continued: Raymond

WCC CREW	**Unit**	**Units**		**$/unit**		**Total $**
WCC Total	***DAY***	***50***	***$***	***500.00***	***$***	***25,000.00***
MAINTENANCE	**Unit**	**Units**		**$/unit**		**Total $**
Mowing	DAYS/YR	0.375	$	456.00	$	171.00
Reseeding	EA	0.25	$	57.00	$	14.25
Maintenance Total					***$***	***185.25***
TOTAL RAYMOND COSTS					**$**	**49,010.90**
COSTS / SQ. FT.	**Unit**	**Units**		**Cost**		**Total/Sq. Ft.**
TOTAL	SQ FT	28075	$	49,010.90	**$**	**1.75**

Table A5: Detailed Costs of Traditional Treatment: Forks (Lost Creek) Site				
MAINTENANCE COSTS	**Unit**	**Units**	**$/unit**	**Total $**
Air Trol (fy 98-99) L.C. Project (Seed/fert/mulch/Air Trol)	Ac.	0.20	$3,851.00	$770.20
Erosion Control (fy 98-99) L.C. Project (hay berms, plastic & ditching)	Ea.	0.14	$111,000.00	$15,540.00
Ditching (fy 99-00) Forks Maint.	Days/Yr.	0.14	$2,100.00	$294.00
Erosion Control(fy 99-00) Forks Maint.	Days/Yr.	0.07	$2,100.00	$147.00
Annual Cost				$441.00
Special Costs 98-99 & 99-00				$16,751.20
PV (LifeCycle)				***$22,744.53***
COSTS W/TRADITIONAL TREATMENT				
Sediment Reduction	**Unit**	**Units**	**$/unit**	**Total $**
Rills	CU YD	77		
Surface erosion	CU YD	0.62		
Total cubic yards		77		
Pond construction quarry spalls	CU YD	424	$10.00	$4,240.00
Culvert installation				
Excavation (35 cubic meters)	CU Meter	35	$10.00	$350.00
Culvert pipe (30m)	Meter	30	$81.50	$2,445.00
Gravel trap	EA	1	$3,500.00	$3,500.00
Inlet grate	EA	2	$1,600.00	$3,200.00
Catch basin	EA	2	$1,250.00	$2,500.00
Drop inlet	EA	2	$4,030.00	$8,060.00
Rill packing with quarry spall	CU FT	231	$19.00	$4,379.50
Rock apron (installed)	FT	180	$75.00	$13,500.00
Erosion Control				
Straw tubing (installed)	FT	400	$7.29	$2,916.00
Wooden Stakes	BN	4	$9.36	$37.44
Airtrol*	EA	1	$3,851.00	$3,851.00
Total Sediment Reduction Costs				***$48,978.94***
Subtotal Cost (PV)				***$71,723.47***
Mobilization Cost				*$7,172.35*
Total Cost (PV) (including 6% sales tax)				***$86,785.40***

* Airtrol is needed to seed the pond and vicinity.

Table A6: Detailed Costs of Soil Bioengineering Treatment: Forks (Lost Creek) Site

MATERIALS	**Unit**	**Units**		**$/unit**		**Total $**
Drain Rock 2.25"	YD	1	$	23.00	$	23.00
Sandy Loam Soil	YD	4.65	$	14.00	$	65.10
Wooden Stakes 2"x2"x36"	BD	7	$	14.99	$	104.93
Compost, GroCo	CU YD	80	$	40.00	$	3,200.00
Native seed	LB	6.3	$	29.01	$	182.76
Annual Rye grass seed	LB	10	$	0.40	$	4.00
Misc.			$	17.79	$	17.79
Supplies Total					***$***	***3,597.58***
PLANT MATERIAL TOTAL*	(installed)				***$***	***944.88***
OPERATION & MAINTENANCE					***$***	***2,362.20***
GEOTECH TREATMENT	**Unit**	**Units**		**$/unit**		**Total $**
Rill packing with quarry spall	CU FT	80	$	19.00	$	1,520.00
Rock apron (installed)	FT	180	$	75.00	$	13,500.00
Geotech Total					***$***	***15,020.00***
WSDOT PERSONNEL	**Unit**	**Units**		**$/unit**		**Total $**
Inspection	DAY	26.25	$	124.80	$	3,276.00
Per Diem	EA	1	$	436.00	$	436.00
TOTAL					***$***	***3,712.00***
WCC CREW	**Unit**	**Units**		**$/unit**		**Total $**
WCC Total	***DAY***	***15***	***$***	***500.00***	***$***	***7,500.00***
TOTAL FORKS COSTS					**$**	**33,136.66**
COSTS / SQ. FT.	**Unit**	**Units**		**Cost**		**Total/Sq. Ft.**
TOTAL	**SQ FT**	**8,660**	**$**	**33,136.66**	**$**	**3.83**

Appendix 4

Methodology of Benefit Assessment

Description of Benefit Analysis

A benefit analysis is basically a method for setting monetary values to the identified benefits of a project. When these values are established, costs and benefits become directly comparable because the same measure (dollars) is being used. Decision makers are then able to make more informed choices. The most challenging aspect of the analysis is to obtain a single, comprehensive value estimate for the collection of effects or to conduct original valuation research, therefore analysts must make assumptions in a professional manner. The quality of the data used should be clearly assessed and reasons for choices should be specifically noted.[30]

Ecosystems provide services that benefit humans. Maintaining and/or improving the health of these systems can have a profound effect on human welfare. However, the benefits of these services are difficult to quantify because natural systems are complex, ecological risks vary depending on the situation, and ecological benefits are not easily converted to monetary values.

Because of these difficulties, this study attempted to maintain simplicity. Benefits were determined by researching similar projects and were chosen because of applicability and available data. For roadside management, benefits determined were roadside stabilization, air pollutant control and uptake, stormwater runoff reduction, and carbon dioxide sequestration. Environmental benefits generated by the projects were assessed using the benefit transfer approach, which is a common method in environmental economic assessment when time and resources are limited (Appendix V has more details). Environmental benefits were derived based on the results and findings of similar studies (Sotir 2001; EPA 1998, California Department of Transportation 1998; McPherson & Simpson 1999) and transferred values were adjusted according to the changes of key factors. Values for these benefits were assessed by the methods described below.

Benefit of Roadside Stabilization

Erosion, sedimentation and dust are problems often associated with transportation projects. Erosion can be gradual or can occur rapidly and can devastate a project. Sediments can cover or destroy important fish habitat and excess deposits can clog harbors or other water transport routes. Dust and other harmful chemicals that become airborne damage air quality. One of the main purposes of most roadside management projects is for stabilization to reduce or eliminate these problems. Therefore, this was considered to be a benefit for this study and a monetary value had to be assessed. In order to determine a monetary value, soil bioengineering was

[30] U.S. EPA. 2000. *Guidelines for Preparing Economic Analyses.* Prepared by the National Center for Environmental Economics. Available online. http://www.epa.gov/economics/

evaluated as an alternative investment option in this analysis. Soil bioengineering projects were designed to produce the same roadside stabilization effect as the traditional approach. Therefore, the cost savings resulting from adoption of soil bioengineering projects was evaluated as a net benefit. The benefit of stabilization was assessed using a cost pricing method for traditional methods. This means that the opportunity cost of the traditional method was treated as a benefit of the soil bioengineering project.

Benefit of Pollutant Control and Uptaking

Creating more roads, often leads to an increase in traffic, which in turn results in higher air pollution. Trees remove pollutants from the atmosphere and also eliminate or reduce the source of pollution. Pollutants deposited and particulates intercepted by trees include Ozone, NO_2, and PM_{10}. Air pollutant uptake benefits were assessed considering a number of factors such as the number of planted trees, growth rate and canopy cover, unit value of pollutant taken and effectiveness. The benefits were estimated using the following formula:

$$B_A \; ? \; ?\, \mathop{?}_{t?1}^{m} \frac{P_t * U_t * N(1 \, ? \, ?_t) * C_t}{(1 \, ? \, i)^t} \, ? * ?$$

Where:
B_A = benefit of pollutant uptaking ($)
P = unit value of pollutant uptaking ($/pound)
U = average pollutant uptaking per tree (pound)
N = number of trees planted
C = Coefficient of canopy cover (percent)
? = mortality rate of planted trees (percent)
i = discount rate (percent)
m = life cycle the method (year)
? = effectiveness of air pollutant uptaking (percent)

Effectiveness was determined by evaluating source elimination and pollutant uptaking effects. The PM_{10} source was virtually eliminated due to re-vegetation, which is a large part of soil bioengineering. Therefore, the effectiveness of reducing PM_{10} is assumed to be 100 percent. The effectiveness of other air pollutants uptaking benefits were estimated based on relative intensity of average daily traffic. The assumption is that heavier traffic leads to more release of pollutants. Consequently, more pollutants are taken up by the trees. The following formula determined the effectiveness of the other air pollutants:

$$? \; ? \; \frac{ADT_j}{ADT_k}$$

Where:
ADT = average daily traffic
j = subscript for project site
k = subscript for urban area

Using these formulas, the pollutant control and uptaking value could be determined for each site.

Benefit of Stormwater Runoff Reduction

As storms pass through an area, the water that is deposited on an impermeable surface (such as a roadway) quickly runs off. This runoff can lead to flooding, erosion, habitat degradation and water quality impairment. Reducing or eliminating runoff is considered a benefit for this study. Stormwater runoff reduction benefits were assessed using runoff coefficients of different land covers, local hydrograph, sediment treatment requirements and the unit value of stormwater treated. These benefits were estimated using the following formula:

$$B_S \; ? \; ?\,?_{t?1}^{m} \; P_t * Q_t * ?^{R_j}\!/\!_{R_k} ? \Big/ ?1 ? i?$$

Where:
B_S = benefit of stormwater runoff reduction ($)
P = unit value of stormwater runoff reduction ($/CF)
Q = stormwater volume (cubic foot)
R_j = runoff coefficient of project site after soil bioengineering treatment (percent)
R_k = runoff coefficient of project site before soil bioengineering treatment (percent)
m = life cycle of the method(year)

Stormwater discharge (Q) was estimated by the following formula:

$$Q \; ? \; 0.28 * R_k * S * A$$

Where:
Q= Stormwater discharge
R_k = runoff coefficient before treatment
S = rainfall intensity
A = total runoff area

The unit value of the stormwater runoff control (P) was adopted from the benefit transfer study reported in 2000.[31] Using these formulas, the beneficial value of stormwater runoff reduction was assessed.

Benefit of Carbon Sequestration

Vehicles emit carbon dioxide into the atmosphere and thus become contributors to climate change. Trees and plants naturally absorb these gases, which creates a benefit to human and ecosystem health. Carbon sequestration can be defined as the net removal of CO_2 from the atmosphere into long-lived pools of carbon. The pools can be living, above-ground biomass (e.g., trees), products with a long, useful life created from biomass (e.g., lumber), living biomass in soils (e.g., roots and microorganisms), or recalcitrant organic and inorganic carbon in soils and deeper subsurface environments. Carbon sequestration benefits for soil bioengineering treatment were estimated using the number of trees planted and the unit value derived from other studies. Carbon sequestration benefits were assessed based on the assumption that 80 percent of carbon will be released at the end of life cycle (removal of trees). Carbon sequestration is not location dependent. Therefore, the effectiveness for the project sites is assumed to be 100 percent of that of study sites.

$$B_C = \left[\sum_{t=1}^{m} \frac{P * U * N(1 - ?)}{(1+i)^t} \right] * ?$$

Where:
B_C = benefit of carbon sequestration ($)
P = unit value of carbon sequestration ($/tree)
U = Average pollutant uptaking per tree[32] (pound)
N = number of trees planted
? ?= mortality rate of planted trees (percent)
i = discount rate (percent)
m = life cycle of the method(year)
? = effectiveness of carbon sequestration (percent)

Using these formulas, the beneficial value of carbon sequestration was assessed.

[31] Xu, George. 2000. Stormwater Benefit Cost Progress Report. Washington State Department of Transportation. Olympia, Washington.
[32] McPherson, E. et.al. 1999. Benefit cost analysis of Modesto's municipal urban forest. *Journal of Arboriculture*. 25(5): 235-248.

Other Benefits

There are many other environmental and aesthetic values that are associated with soil bioengineering treatments. They were not assessed for this study because of lack of base line information, intangibility, or time constraints. For example, some of the additional benefits of trees include beautification, privacy, shade, and wildlife habitat - these were not quantified. Also, the benefit of being able to install projects during the dormant season was also not calculated. Neither were specific ecological benefits such as benefits to fisheries, etc.

As mentioned at the beginning of this section, benefit determinations can be challenging. In this case, it was too expensive and too time consuming to do original research, so the analysts had to draw upon existing values from other studies. Also, an "effect-by-effect" approach, which is the most widely used approach for estimating benefits, involves describing the physical effects of the impacts of the project and assessing each type of effect separately. This would be a major undertaking and would be beyond the scope of this project.

Appendix 5

Benefits

Table A7: Soil Bioengineering For Roadside Management: Benefit Cost Analysis

	CHELAN		RAYMOND		FORKS	
	Life Cycle Benefit	**Annua-lized Benefit**	**Life Cycle Benefit**	**Annua-lized Benefit**	**Life Cycle Benefit**	**Annua-lized Benefit**
Total Benefit:	$76,056	$1,521	$398,835	$7,977	$211,231	$4,225
Cost Saving	$5,843	$117	$398,835	$7,977	$183,827	$3,677
Runoff Control	$2,730	$55			$22,230	$445
Air Pollutant Uptake	$59,305	$1,186			$962	$19
CO2 Sequestration	$8,178	$164			$4,213	$84
Total Costs:	$52,216	$1,044	$49,011	$980	$33,137	$663
Net Benefit:	$23,840	$477	$349,824	$6,996	$178,095	$3,562
B/C Ratio		1.46		8.14		6.37

Table A8: Traditional Treatment For Roadside Management: Benefit Cost Analysis

	CHELAN		RAYMOND		FORKS	
	Life Cycle Benefit	**Annua-lized Benefit**	**Life Cycle Benefit**	**Annua-lized Benefit**	**Life Cycle Benefit**	**Annua-lized Benefit**
Total Benefit:	$35,084	$1,398	$179,139	$8,957	$104,569	$4,695
Stabilization	$23,224	$1,161	$179,139	$8,957	$86,785	$4,339
Runoff Control					$17,784	$356
Air Pollutant Source Control	$11,861	$237				
Total Costs:	$ 23,224	$1,161	$179,139	$8,957	$86,785	$4,339
Net Benefit:	$11,861	$237	$0	$0	$17,784	$356
B/C Ratio		1.20		1.00		1.08

Appendix 6

Benefit Transfer Summary

Benefit Transfer Summary [33]

This method transfers existing benefit estimates from studies already completed for another location or issue to estimate the economic value for the items in question. It is often used when conducting an original valuation study is too expensive or too time consuming. Researchers and analysts who use this method, should keep in mind that the transfers are only as accurate as the initial study. Some of the advantages of this method are:

- typically less costly than an original study
- benefits can be estimated quicker than when undertaking an original valuation study
- can be used as a screening technique to determine whether a more detailed study is needed
- can be used to make easy and quick estimates of recreational values

There are different types of benefit transfer, with the unit-day approach being the simplest. In this approach, existing values for activity days are used to value the same activity at other sites. Expert judgment is used to combine and average benefit estimates from a number of existing studies and then adjusting these values for site-specific characteristics. A more rigorous approach involves transferring a benefit function from another study. In this approach, the benefit function statistically relates peoples' willingness to pay to characteristics of the ecosystem and the people whose values were elicited. This allows for more precision because adjustments can be made for different characteristics.

For different contexts, different standards can be applied. For example, when the costs of making a poor decision are higher, a higher standard of accuracy may be required. When costs are lower, such as when it is used as a screening tool for the early stage of a policy analysis, a lower standard of accuracy may be acceptable.

The benefit transfer method is most reliable when the original site and the study site are very similar in terms of factors such as quality, location, and population characteristics; when the environmental change is very similar for the two sites; and when the original valuation study was carefully conducted and used sound valuation techniques.

Applying the benefit transfer method involves several steps. Existing studies or values need to be identified first. Next, the existing values need to be evaluated to determine whether they can be transferable. The quality of the studies to be transferred should also be evaluated. Then, the existing values should be adjusted to better reflect the value for the site under consideration. Finally, the total value is estimated by multiplying the transferred values by the number of affected people.

[33] Adapted from King and Mazzotta. Ecosystem Valuation website. Methods, Section 8: Benefit Transfer Method

This method has issues and limitations as well. They are as follows:

- May not be accurate unless the sites share all of the characteristics
- Good studies for the specific question may not be available
- Appropriate studies may be difficult to track down since many are not published
- Reporting of existing studies may be inadequate to make the needed adjustments
- Adequacy of existing studies may be difficult to assess
- Extrapolation beyond the range of the initial study is not recommended
- Transfers are only as accurate as the initial value estimate
- Estimates of unit values can become dated very quickly